# Schedule Uncertainty Analysis Using Historical Data

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# Outline

- Background/Purpose
- Methodology
- Data Analysis
- Simulation Models
- Results
- Conclusions

# Background/Purpose

- At life cycle reviews and key decision points, NASA projects are required to provide risk-informed schedule, schedule-adjusted cost, and joint cost and schedule confidence levels.
- The Standing Review Boards (SRB) are charged with assessing the adequacy of the integrated cost and schedule estimate and funding strategy. This requires the SRB programmatic analyst to do independent cost and schedule assessments.
- As part of the independent programmatic assessment, an Independent Schedule Estimate (ISE) can be developed
- The generally accepted practice for schedule risk assessment consists of two parts:
  - Schedule uncertainty – general uncertainty about the duration of activities
  - Discrete risks – specific things that can go wrong
- There are three generally accepted methods for estimating schedule uncertainty:
  - Subject Matter Experts (SME) provide probability distribution functions (PDF)
  - Actual project performance data is used to estimate PDFs
  - Historical schedule data from similar projects is used to estimate PDFs
- This paper demonstrates a method for estimating schedule uncertainty using analogous historical data.

# Methodology

- Collect top-level schedule data on major milestones for spacecraft projects
- Filter the data for analogous missions
- Calculate the duration between major milestones
- Fit PDF curves to the duration data
- Calculate the correlation between phases
- Build level 1 and level 2 simulation models
  - Level 1 = duration from PDR to Launch
  - Level 2 = sum of durations: PDR to CDR, CDR to I&T, I&T to Launch
- Run the simulation models and produce schedule s-curves

# DATA ANALYSIS

# Data Source

- The source of data for this study is the "Master List Project Schedule Milestones July 15, 2013" Excel file.
- This file is maintained by the Cost Analysis Division (CAD) at NASA HQ.
- This file contains schedule data for major milestones for over 290 NASA projects.
- Milestones collected are: ATP, SRR, PDR, CR, CDR, I&T Start, PER, PSR, Launch, EoM, EoeM
- Only missions that have launched or plan to launch soon are included in the database. There are no cancelled projects in the data.
- For various reasons, many projects do not have a complete set of milestone dates.

| Project | ATP | SRR | PDR | CR | CDR | I&T Start | PER | PSR | Launch |
|---|---|---|---|---|---|---|---|---|---|
| ACE | 10/1/1993 | 11/1/1992 | 11/1/1993 | 9/1/1993 | 10/1/1994 | 4/24/1996 | 1/7/1997 | 6/10/1997 | 8/25/1997 |
| ACRIMSAT | | 3/16/1996 | 12/1/1997 | | 2/1/1998 | | | | 12/21/1999 |
| ACTS | 8/1/1984 | 7/15/1985 | 5/15/1986 | | 5/15/1988 | 6/1/1991 | 4/1/1992 | 6/1/1992 | 9/1/1993 |
| AE-C | 10/1/1971 | | 2/1/1972 | | 8/1/1972 | | | | 12/13/1973 |
| AEM-HCMM | 12/1/1974 | | | | | | | | 4/26/1978 |
| AIM | | 5/22/2003 | 1/28/2004 | 4/28/2004 | 10/27/2004 | 10/27/2004 | 4/6/2006 | 2/26/2007 | 4/25/2007 |
| AMPTE | 2/1/1982 | | | | 11/1/1982 | | | | 8/16/1984 |
| Apollo CSM | 7/1/1962 | | 1/6/1965 | | 2/6/1965 | | | | 10/11/1968 |
| Apollo LEM | 1/1/1963 | | 9/1/1963 | | 1/1/1966 | | | | 3/3/1969 |
| Aqua (PM-1) | 8/1/1993 | | 4/30/1997 | | 6/19/1998 | 7/1/1998 | 2/16/2000 | 2/5/2002 | 5/4/2002 |
| Aquarius | | 8/12/2004 | 5/28/2005 | 9/28/2005 | 7/21/2008 | 6/1/2009 | 6/26/2010 | 3/2/2011 | 6/9/2011 |
| ARES I (Constellation) | | 12/19/2006 | Delta PDR | /07 | cancelled | cancelled | cancelled | cancelled | 6/15/2014 |
| Aspera-3 | Instrument on Mars Express | | | 9/5/2000 | 5/1/2000 | | | | 6/2/2003 |
| Astro-1 | Shuttle Mission | | | | | | | | 12/2/1990 |
| Astro-2 | Shuttle Mission | | | | | | | | 3/2/1995 |
| **ASTRO-E** | ailed Mission | | | | | | | | 7/10/2005 |
| Astro-E2 / SUZAKU | 07/2001 | | 09/2001 | 3/2002 | 4/12/2002 | | | | 7/9/2005 |
| **Astro-H** | 6/20/2008 | 12/15/2008 | 3/10-11/2010 | | 11/16/2011 | N/A | 10/14/2012 | 4/1/2014 | 8/15/2015? |
| ATS-1 Applications techn Sat | 2/1964 | | | | | | | | 12/7/1966 |
| Technology Satellite) | 4/1967 | | | | | | | | 4/6/1967 |
| ATS-3 | | | | | | | | | 11/5/1967 |
| ATS-4 | | | | | | | | | 8/10/1967 |
| (Applications Technology Sa | 8/1969 | | | | | | | | 8/12/1969 |
| (Applications Technology Sa | 5/1974 | | | | | | | | 5/15/1974 |
| Aura (Chem-1) or Chemistry | 8/1/1993 | 7/1/1999 | 11/16/1999 | | 9/12/2000 | 10/1/2001 | 4/2/2003 | 3/4/2004 | 7/15/2004 |
| BARREL | 12/1/2007 | 5/8/2008 | 3/26/2010 | 4/1/2010 | 1Q2011 | oon Experin | oon Experin | oon Experin | 4Q2013 |
| CALIPSO | 12/1/1998 | 1/15/2000 | 9/18/2000 | 9/15/2000 | 4/15/2003 | 3/1/2004 | 8/1/2004 | 5/19/2005 | 4/28/2006 |
| Cassini | 1/1/1990 | 8/1/1988 | 8/11/1992 | | 12/9/1992 | | | | 10/15/1997 |
| Chandra | 1/1/1989 | 12/1/1992 | 11/1/1994 | | 2/1/1996 | 10/1/1997 | 10/1/1998 | 2/4/1999 | 7/23/1999 |
| CHIPSAT | | 9/1/1999 | 9/1/2000 | 12/1/2000 | 4/18/2001 | 6/1/2002 | 8/15/2002 | 10/6/2002 | 1/12/2003 |
| CINDI | | 5/10/2000 | 6/19/2001 | 11/14/2001 | 6/25/2002 | | | | 4/16/2008 |
| Clark | Cancelled | | Cancelled | | | | | | |
| **CLARREO** | 2/1/2011 | ended Pre-P | TBD | | TBD | TBD | | TBD | TBD |
| Clementine | 2/15/1992 | 6/15/1992 | 9/15/1992 | | 12/15/1992 | | | | 1/25/1994 |
| CloudSat | 4/1/1999 | 2/29/2000 | 9/1/2000 | 11/15/2000 | 8/1/2001 | | | 7/1/2004 | 4/28/2006 |
| Cluster | | 9/1/1989 | | | | | | | 6/4/1996 |
| Cluster-2 (Rumba & Tengo) | one of two la | 9/1/1989 | ATP immediately after Cluster 1 destroyed at launch. These are Replicas | | | | | | 8/9/2000 |
| Cluster-2 (Salsa & Samba) | one of two la | 9/1/1989 | ATP immediately after Cluster 1 destroyed at launch. These are Replicas | | | | | | 7/16/2000 |
| COBE | 7/1/1982 | 7/15/1982 | 10/11/1983 | | 5/1/1987 | 9/1/1988 | 12/1/1988 | 9/15/1989 | 11/18/1989 |
| CONTOUR | 10/1/1997 | 5/19/1999 | 1/19/2000 | 2/3/2000 | 12/12/2000 | 2/1/2002 | 1/8/2002 | 4/19/2002 | 7/3/2002 |
| Constellation Integration | | 11/14/2006 | 3/4-5/2010 | OR: 6/18/20 | cancelled | cancelled | cancelled | cancelled | |

# Data Filtering

- The schedule database was filtered for projects with the theme “Planetary” or “Planetary (Mars).”
- Projects that do not have PDR or Launch dates are excluded.
- Galileo was excluded because it was twice as long as any other project due to delays related to the Space Shuttle Challenger disaster.
- Redundant data points are excluded (e.g. Viking Lander B, Viking Orbiter).

# Selected Missions

- Cassini
- CONTOUR
- DAWN
- Deep Impact
- Genesis
- GRAIL
- JUNO
- LADEE
- Lunar Prospector
- MAGELLAN
- Mars Express
- Mars Observer
- Mars Odyssey 01
- Mars Pathfinder
- Mars Polar Lander (MPL)
- MAVEN
- MCO
- MER-A (SPIRIT)
- MER-B (Opportunity)
- MESSENGER
- MGS
- MMM (M3) on Chandrayaan-1
- MRO
- MSL
- NEAR
- New Horizons
- OSIRIS-REX
- Phoenix
- STARDUST
- Ulysses
- Viking Lander A
- Voyager 1

# Data Set

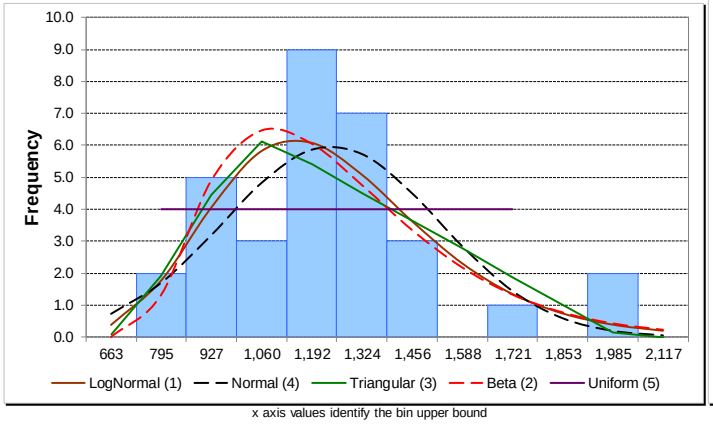
| Observations | Variable 1 | Variable 2 | Variable 3 | Variable 4 | Variable 5 | Variable 6 | Variable 7 | Variable 8 | Variable 9 | Variable 10 | Variable 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable ID | DaysATPtoSRR | DaysSRRtoPDR | DaysPDRtoCDR | DaysCDRtoI&T | DaysI&TtoLaunch | DaysATPto Launch | DaysSRRto Launch | DaysPDRto Launch | DaysCDRto Launch | DaysI&TtoL aunchNoOu tliers | DaysPDRto LaunchNoO utliers |
| Cassini | | 1471 | 120 | | | 2844 | 3362 | 1891 | 1771 | | |
| CONTOUR | 595 | 245 | 328 | 416 | 152 | 1736 | 1141 | 896 | 568 | | 896 |
| DAWN | | 198 | 245 | 217 | 980 | | 1640 | 1442 | 1197 | | |
| Deep Impact | | 285 | 339 | 468 | 609 | | 1701 | 1416 | 1077 | 609 | |
| Genesis | 142 | 119 | 331 | 138 | 646 | 1376 | 1234 | 1115 | 784 | 646 | 1115 |
| GRAIL | | 317 | 364 | 255 | 411 | | 1347 | 1030 | 666 | 411 | 1030 |
| JUNO | | 897 | 342 | 346 | 491 | 2076 | 2076 | 1179 | 837 | 491 | 1179 |
| LADEE | | 366 | 299 | | | | 1482 | 1116 | 817 | | 1116 |
| Lunar Prospector | | | 92 | | | 1011 | | 875 | 783 | | 875 |
| MAGELLAN | | 536 | 397 | | | 2012 | 2212 | 1676 | 1279 | | |
| Mars Express | | | 90 | | | | | 1217 | 1127 | | 1217 |
| Mars Observer | | 2632 | 504 | | 1304 | 2308 | 3861 | 1229 | 725 | | 1229 |
| Mars Odyssey 01 | | 130 | 186 | | | | 1041 | 911 | 725 | | 911 |
| Mars Pathfinder | | 261 | 414 | | | 1160 | 1494 | 1233 | 819 | | 1233 |
| Mars Polar Lander (MPL) | | 111 | 581 | | | | 1404 | 1293 | 712 | | 1293 |
| MAVEN | 310 | 339 | 364 | 350 | 511 | 1874 | 1564 | 1225 | 861 | 511 | 1225 |
| MCO | | 245 | 447 | | | | 1371 | 1126 | 679 | | 1126 |
| MER-A (SPIRIT) | | 97 | 310 | 186 | 470 | | 1063 | 966 | 656 | 470 | 966 |
| MER-B (Opportunity) | | 97 | 310 | 221 | 463 | | 1091 | 994 | 684 | 463 | 994 |
| MESSENGER | 153 | 387 | 299 | 292 | 576 | 1707 | 1554 | 1167 | 868 | 576 | 1167 |
| MGS | 56 | 155 | 251 | | | 996 | 940 | 785 | 534 | | 785 |
| MMM (M3) on Chandrayaan-1 | | 48 | 256 | 457 | 434 | | 1195 | 1147 | 891 | 434 | 1147 |
| MRO | 106 | 190 | 302 | 329 | 484 | 1411 | 1305 | 1115 | 813 | 484 | 1115 |
| MSL | 223 | 192 | 346 | 274 | 1365 | 2400 | 2177 | 1985 | 1639 | | |
| NEAR | | | 219 | 186 | 258 | 869 | | 663 | 444 | | 663 |
| New Horizons | | 160 | 374 | | | | 1345 | 1185 | 811 | | 1185 |
| OSIRIS-REX | 353 | 296 | 406 | 307 | 579 | 1941 | 1588 | 1292 | 886 | 579 | 1292 |
| Phoenix | | 349 | 252 | 147 | 481 | | 1229 | 880 | 628 | 481 | 880 |
| STARDUST | 106 | 192 | 264 | 205 | 397 | 1164 | 1058 | 866 | 602 | 397 | 866 |
| Ulysses | 379 | 2725 | 457 | | | 4388 | 4009 | 1284 | 827 | | 1284 |
| Viking Lander A | | | 670 | | | 1967 | | 1419 | 749 | | |
| Voyager 1 | | 1189 | 271 | | | 2043 | 2258 | 1069 | 798 | | 1069 |

# Data Analysis – Curve Fitting Methodology

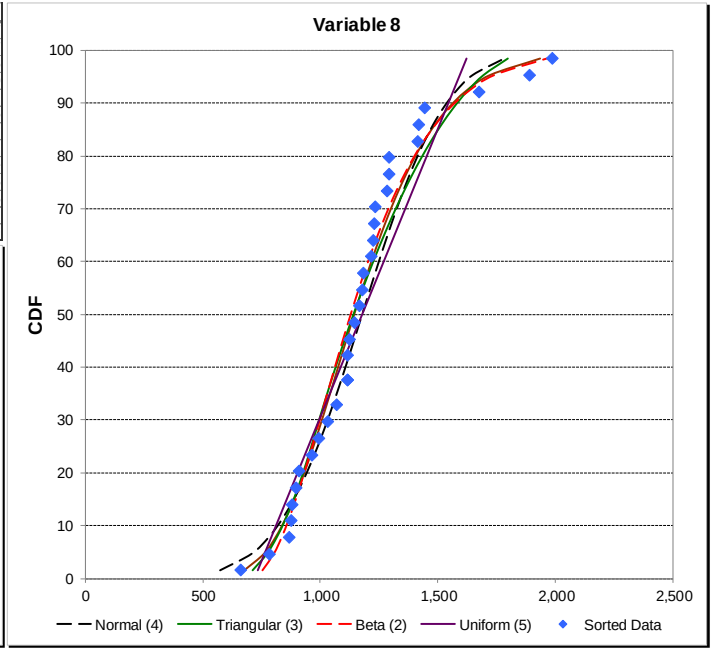
- Calculate calendar days duration between major milestones:
  - Days from PDR to Launch
  - Days from PDR to CDR
  - Days from CDR to I&T Start
  - Days from I&T Start to Launch
- Using a statistical data analysis tool called CO$TAT, find the distribution shape that most closely matches the data.
- Lognormal, Normal, Triangular, Beta and Uniform distributions are assessed against the selected data.
- The sum of squared error (SSE) method was used to fit the distributions to the data set.

# Curve Fit - PDR to Launch

| | Sample | LogNormal | Normal | Triangular | Beta | Uniform |
|---|---|---|---|---|---|---|
| Mean | 1,177.7188 | 1,178.4256 | 1,177.7140 | 1,177.8790 | 1,179.4018 | 1,177.7187 |
| StdDev | 290.4668 | 291.7406 | 280.3910 | 277.4916 | 288.1516 | 264.5037 |
| CV | 0.2466 | 0.2476 | 0.2381 | 0.2356 | 0.2443 | 0.2246 |
| Min | 663.0000 | | | 628.7257 | 670.4596 | 719.5849 |
| Mode | 1,115.0000 | 1,077.8320 | 1,177.7140 | 966.8299 | 1,016.8908 | |
| Max | 1,985.0000 | | | 1,938.0815 | 6,689.0033 | 1,635.8526 |
| Alpha | | | | | 2.7712 | |
| Beta | | | | | 30.0000 | |
| Data Count | 32 | % < 0 = | 0.00% | None | None | None |
| Standard Error of Estimate | | 55.8306 | 81.1819 | 77.8472 | 57.7336 | 112.4435 |
| Rank | | 1 | 4 | 3 | 2 | 5 |
| SEE / Fit Mean | | 4.74% | 6.89% | 6.61% | 4.90% | 9.55% |
| Chi^2 Fit test 8 Bins, Sig 0.05 | | Good (16%) | Good (42%) | Good (16%) | Good (48%) | Good (6%) |



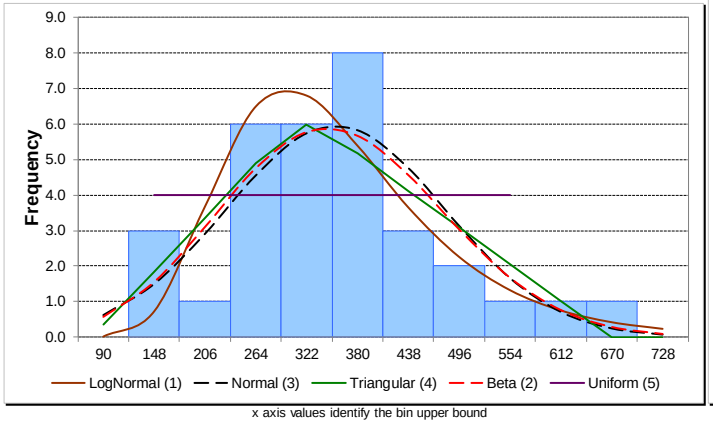

x axis values identify the bin upper bound



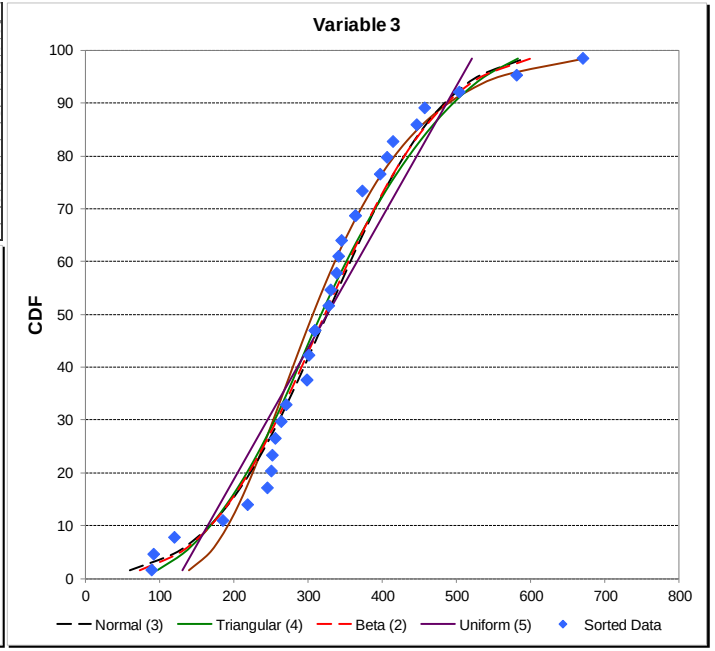

| SPECIFICATION | |
|---|---|
| Variable | Variable 8 |
| ID | DaysPDRtoLaun |
| Percentile | AutoCalc |
| Min Method | SSE |
| Min On | Values |
| Weighting | None |
| Filter | None |
| | |
| MEAN = SAMPLE MEAN | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| STDEV = SAMPLE STDEV | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| LOW BOUNDS | |
| LogNormal | N/A |
| Normal | Unconstrained |
| Triangular | Unconstrained |
| Beta | Unconstrained |
| Uniform | Unconstrained |
| | |
| SURROUND | |
| LogNormal | N/A |
| Normal | N/A |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |

# Curve Fit - PDR to CDR

| | Sample | LogNormal | Normal | Triangular | Beta | Uniform |
|---|---|---|---|---|---|---|
| Mean | 325.9375 | 327.6903 | 325.9386 | 325.9688 | 325.8424 | 325.9375 |
| StdDev | 125.4658 | 123.6420 | 123.3971 | 121.0827 | 123.3159 | 116.1943 |
| CV | 0.3849 | 0.3773 | 0.3786 | 0.3715 | 0.3785 | 0.3565 |
| Min | 90.0000 | | | 50.2655 | -348.3794 | 124.6831 |
| Mode | 299.0000 | 268.3835 | 325.9386 | 287.8747 | 316.4153 | |
| Max | 670.0000 | | | 639.7663 | 1,435.6466 | 527.1919 |
| Alpha | | | | | 18.2178 | |
| Beta | | | | | 29.9874 | |
| Data Count | 32 | % < 0 = | 0.41% | None | 0.19% | None |
| Standard Error of Estimate | | 24.6481 | 25.7159 | 28.6986 | 25.5153 | 43.4418 |
| Rank | | 1 | 3 | 4 | 2 | 5 |
| SEE / Fit Mean | | 7.52% | 7.89% | 8.80% | 7.83% | 13.33% |
| Chi^2 Fit test 8 Bins, Sig 0.05 | | Good (42%) | Good (36%) | Good (48%) | Good (32%) | Good (16%) |



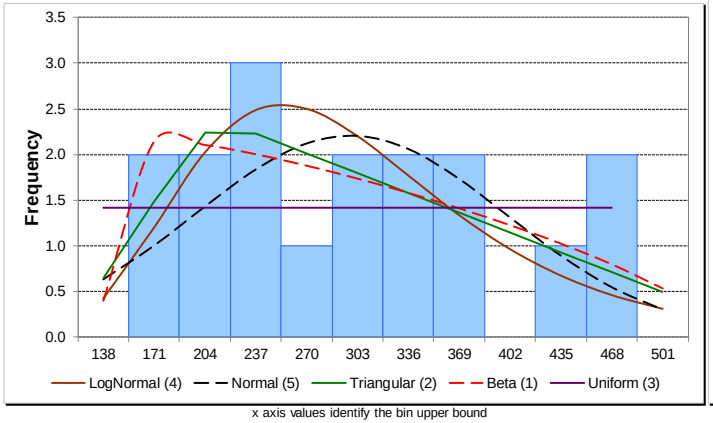

x axis values identify the bin upper bound



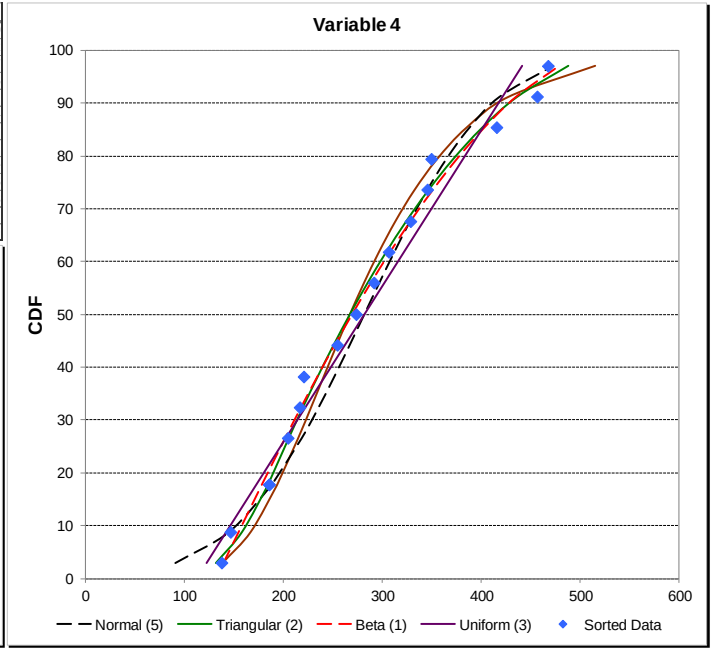

| SPECIFICATION | |
|---|---|
| Variable | Variable 3 |
| ID | DaysPDRtoCDR |
| Percentile | AutoCalc |
| Min Method | SSE |
| Min On | Values |
| Weighting | None |
| Filter | None |
| | |
| MEAN = SAMPLE MEAN | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| STDEV = SAMPLE STDEV | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| LOW BOUNDS | |
| LogNormal | N/A |
| Normal | Unconstrained |
| Triangular | Unconstrained |
| Beta | Unconstrained |
| Uniform | Unconstrained |
| | |
| SURROUND | |
| LogNormal | N/A |
| Normal | N/A |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |

# Curve Fit – CDR to I&T Start

| | Sample | LogNormal | Normal | Triangular | Beta | Uniform |
|---|---|---|---|---|---|---|
| **Mean** | 282.0000 | 283.9363 | 281.9280 | 282.1381 | 282.2157 | 282.0000 |
| **StdDev** | 102.1310 | 101.6207 | 100.9969 | 99.7265 | 99.1920 | 97.7762 |
| **CV** | 0.3622 | 0.3579 | 0.3582 | 0.3535 | 0.3515 | 0.3467 |
| **Min** | 138.0000 | | | 95.8465 | 131.4748 | 112.6466 |
| **Mode** | 186.0000 | 236.9758 | 281.9280 | 191.8614 | 156.5016 | |
| **Max** | 468.0000 | | | 558.7064 | 526.7032 | 451.3534 |
| **Alpha** | | | | | 1.0472 | |
| **Beta** | | | | | 1.6985 | |
| **Data Count** | 17 | **% < 0 =** | 0.26% | None | None | None |
| **Standard Error of Estimate** | | 19.8923 | 20.7527 | 12.1107 | 11.9985 | 18.4926 |
| **Rank** | | 4 | 5 | 2 | 1 | 3 |
| **SEE / Fit Mean** | | 7.01% | 7.36% | 4.29% | 4.25% | 6.56% |
| **Chi^2 Fit test 6 Bins, Sig 0.05** | | Good (64%) | Good (49%) | Good (21%) | Good (32%) | Good (49%) |



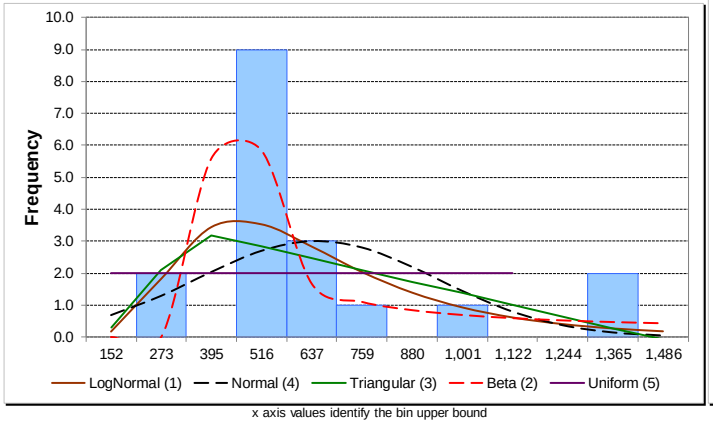

x axis values identify the bin upper bound



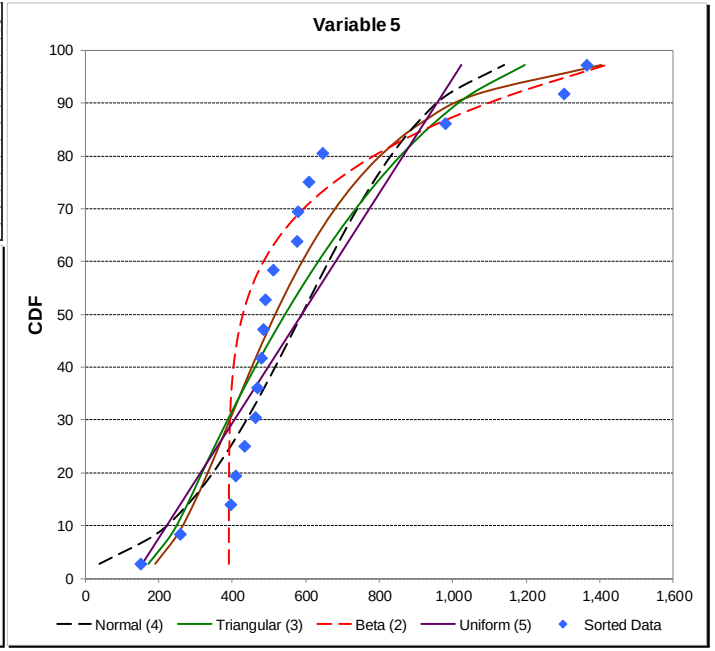

| **SPECIFICATION** | |
|---|---|
| Variable | Variable 4 |
| ID | DaysCDRtoI&T |
| Percentile | AutoCalc |
| Min Method | SSE |
| Min On | Values |
| Weighting | None |
| Filter | None |
| | |
| **MEAN = SAMPLE MEAN** | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| **STDEV = SAMPLE STDEV** | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| **LOW BOUNDS** | |
| LogNormal | N/A |
| Normal | Unconstrained |
| Triangular | Unconstrained |
| Beta | Unconstrained |
| Uniform | Unconstrained |
| | |
| **SURROUND** | |
| LogNormal | N/A |
| Normal | N/A |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |

# Curve Fit – I&T Start to Launch

| | Sample | LogNormal | Normal | Triangular | Beta | Uniform |
|---|---|---|---|---|---|---|
| Mean | 589.5000 | 592.7094 | 589.5000 | 590.0521 | 590.1902 | 589.5000 |
| StdDev | 319.1637 | 331.6551 | 287.6735 | 288.4371 | 298.2548 | 265.3791 |
| CV | 0.5414 | 0.5596 | 0.4880 | 0.4888 | 0.5054 | 0.4502 |
| Min | 152.0000 | | | 86.7438 | 391.0956 | 129.8498 |
| Mode | | 393.9062 | 589.5000 | 285.6610 | | |
| Max | 1,365.0000 | | | 1,397.7515 | 1,562.9700 | 1,049.1502 |
| Alpha | | | | | 0.2000 | |
| Beta | | | | | 0.9772 | |
| Data Count | 18 | % < 0 = | 2.02% | None | None | None |
| Standard Error of Estimate | | 98.3849 | 146.5231 | 133.0706 | 105.2432 | 171.0182 |
| Rank | | 1 | 4 | 3 | 2 | 5 |
| SEE / Fit Mean | | 16.60% | 24.86% | 22.55% | 17.83% | 29.01% |
| Chi^2 Fit test 6 Bins, Sig 0.05 | | Poor (3%) | Poor (3%) | Poor (1%) | Poor (0%) | Poor (1%) |




x axis values identify the bin upper bound

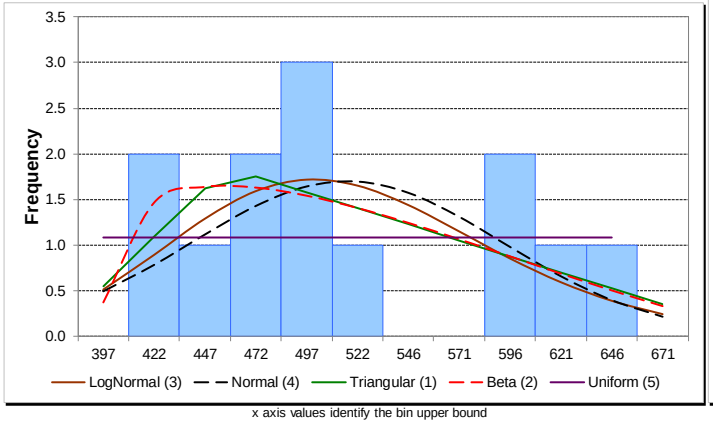



| SPECIFICATION | |
|---|---|
| Variable | Variable 5 |
| ID | DaysI&TtoLaunc |
| Percentile | AutoCalc |
| Min Method | SSE |
| Min On | Values |
| Weighting | None |
| Filter | None |
| | |
| MEAN = SAMPLE MEAN | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| STDEV = SAMPLE STDEV | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| LOW BOUNDS | |
| LogNormal | N/A |
| Normal | Unconstrained |
| Triangular | Unconstrained |
| Beta | Unconstrained |
| Uniform | Unconstrained |
| | |
| SURROUND | |
| LogNormal | N/A |
| Normal | N/A |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |

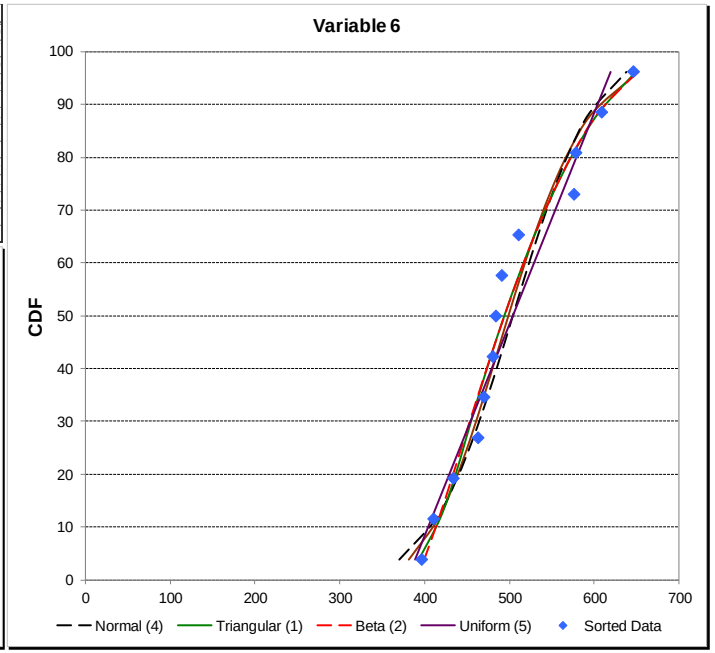
# Curve Fit – I&T Start to Launch – No Outliers

- I&T to Launch exhibited poor fit characteristics, so 5 extreme data points were removed and another distribution was calculated

| | Sample | LogNormal | Normal | Triangular | Beta | Uniform |
|---|---|---|---|---|---|---|
| Mean | 504.0000 | 504.5063 | 504.0000 | 504.1704 | 504.3960 | 504.0000 |
| StdDev | 76.9090 | 76.9413 | 75.6320 | 74.2609 | 74.1818 | 72.0657 |
| CV | 0.1526 | 0.1525 | 0.1501 | 0.1473 | 0.1471 | 0.1430 |
| Min | 397.0000 | | | 359.1930 | 387.5126 | 379.1786 |
| Mode | | 487.4032 | 504.0000 | 445.0375 | 443.4828 | |
| Max | 646.0000 | | | 708.2806 | 728.5443 | 628.8214 |
| Alpha | | | | | 1.2890 | |
| Beta | | | | | 2.4719 | |
| Data Count | 13 | % < 0 = | 0.00% | None | None | None |
| Standard Error of Estimate | | 15.0928 | 17.9827 | 13.5439 | 14.6345 | 18.7434 |
| Rank | | 3 | 4 | 1 | 2 | 5 |
| SEE / Fit Mean | | 2.99% | 3.57% | 2.69% | 2.90% | 3.72% |
| Chi^2 Fit test 6 Bins, Sig 0.05 | | Good (37%) | Good (53%) | Good (8%) | Poor (3%) | Good (17%) |




x axis values identify the bin upper bound




| SPECIFICATION | |
|---|---|
| Variable | Variable 6 |
| ID | DaysI&TtoLaunc |
| Percentile | AutoCalc |
| Min Method | SSE |
| Min On | Values |
| Weighting | None |
| Filter | None |
| | |
| MEAN = SAMPLE MEAN | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| STDEV = SAMPLE STDEV | |
| LogNormal | Off |
| Normal | Off |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |
| | |
| LOW BOUNDS | |
| LogNormal | N/A |
| Normal | Unconstrained |
| Triangular | Unconstrained |
| Beta | Unconstrained |
| Uniform | Unconstrained |
| | |
| SURROUND | |
| LogNormal | N/A |
| Normal | N/A |
| Triangular | Off |
| Beta | Off |
| Uniform | Off |

# Summary of Selected Distributions

| | Days PDR to Launch | Days PDR to CDR | Days CDR to I&T | Days I&T to Launch | Days I&T to Launch No Outliers |
|---|---|---|---|---|---|
| Distribution | LogNormal | LogNormal | Triangular | LogNormal | LogNormal |
| Mean | 1,178 | 328 | 282 | 593 | 505 |
| StdDev | 292 | 124 | 100 | 332 | 77 |
| CV | 0.25 | 0.38 | 0.35 | 0.56 | 0.15 |
| Min | | | 96 | | |
| Mode | 1,078 | 268 | 192 | 394 | 487 |
| Max | | | 559 | | |
| Alpha | | | | | |
| Beta | | | | | |
| Data Count | 32 | 32 | 17 | 18 | 13 |
| Standard Error of Estimate | 56 | 25 | 12 | 98 | 15 |
| Rank | 1 | 1 | 2 | 1 | 3 |
| SEE / Fit Mean | 4.74% | 7.52% | 4.29% | 16.60% | 2.99% |
| Chi^2 Fit test 8 Bins, Sig 0.05 | Good (16%) | Good (42%) | Good (21%) | Poor (3%) | Good (37%) |

- LogNormal distribution was selected for all phases except CDR to I&T

# Correlation Matrix

**Pairwise Variable Analysis For Dataset New Dataset**

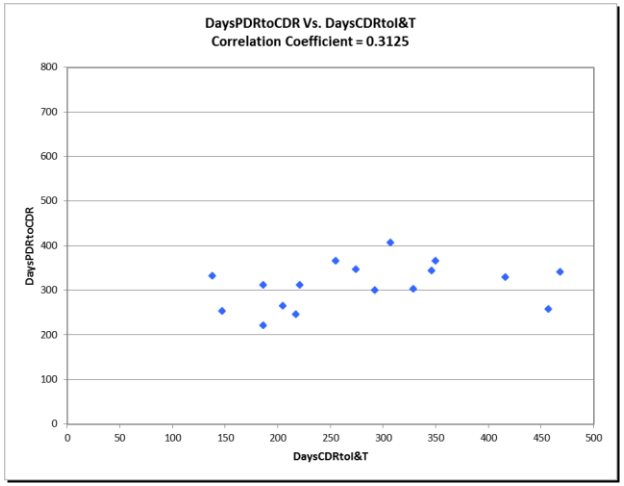
Thursday, 05 September 2013, 10:48 am

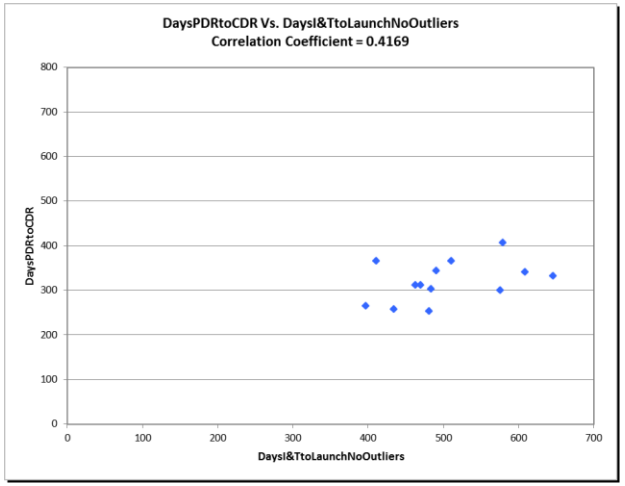
**I. Correlation Matrix**

| | DaysATPtoSRR | DaysSRRtoPDR | DaysPDRtoCDR | DaysCDRtoI&T | DaysI&TtoLaunch | DaysATPtoLaunch | DaysSRRtoLaunch | DaysPDRtoLaunch | DaysCDRtoLaunch | DaysI&TtoLaunchNoOutliers | DaysPDRtoLaunchNoOutliers |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **DaysATPtoSRR** | 1.0000 | 0.3227 | 0.6081 | 0.7141 | -0.3414 | 0.4700 | 0.3192 | 0.0930 | -0.0222 | 0.2837 | 0.2413 |
| **DaysSRRtoPDR** | 0.3227 | 1.0000 | 0.2363 | 0.1733 | 0.5114 | 0.7876 | 0.9394 | 0.2284 | 0.1453 | 0.0755 | 0.2530 |
| **DaysPDRtoCDR** | 0.6081 | 0.2363 | 1.0000 | 0.3125 | 0.4750 | 0.3293 | 0.2336 | 0.2371 | -0.1966 | 0.4169 | 0.5421 |
| **DaysCDRtoI&T** | 0.7141 | 0.1733 | 0.3125 | 1.0000 | -0.1203 | 0.5614 | 0.2693 | 0.2863 | 0.2479 | 0.0791 | 0.4434 |
| **DaysI&TtoLaunch** | -0.3414 | 0.5114 | 0.4750 | -0.1203 | 1.0000 | 0.7104 | 0.7670 | 0.7884 | 0.7192 | 1.0000 | 0.6365 |
| **DaysATPtoLaunch** | 0.4700 | 0.7876 | 0.3293 | 0.5614 | 0.7104 | 1.0000 | 0.8592 | 0.5695 | 0.4558 | 0.2416 | 0.5807 |
| **DaysSRRtoLaunch** | 0.3192 | 0.9394 | 0.2336 | 0.2693 | 0.7670 | 0.8592 | 1.0000 | 0.5482 | 0.4577 | 0.4048 | 0.4556 |
| **DaysPDRtoLaunch** | 0.0930 | 0.2284 | 0.2371 | 0.2863 | 0.7884 | 0.5695 | 0.5482 | 1.0000 | 0.9059 | 0.6574 | 1.0000 |
| **DaysCDRtoLaunch** | -0.0222 | 0.1453 | -0.1966 | 0.2479 | 0.7192 | 0.4558 | 0.4577 | 0.9059 | 1.0000 | 0.6274 | 0.7703 |
| **DaysI&TtoLaunchNoOutliers** | 0.2837 | 0.0755 | 0.4169 | 0.0791 | 1.0000 | 0.2416 | 0.4048 | 0.6574 | 0.6274 | 1.0000 | 0.6574 |
| **DaysPDRtoLaunchNoOutliers** | 0.2413 | 0.2530 | 0.5421 | 0.4434 | 0.6365 | 0.5807 | 0.4556 | 1.0000 | 0.7703 | 0.6574 | 1.0000 |

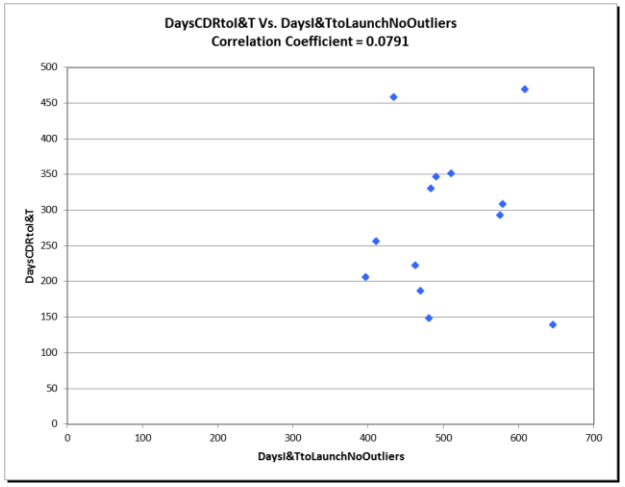
- The report shows a correlation matrix for all the data points in the data set.
- The numbers that are highlighted represent the correlation between phases of interest for this project.
- For example, for the data above, we want to know the correlation between PDR to CDR, CDR to I&T, and I&T to Launch.

# Correlation Scatter Plots




- The scatter plots show that weak correlation exists between phases.



# Examination of Possible Outliers

**MSL**

1st longest duration from PDR to Launch (1985 days, 64 months).

Removing this data point would reduce mean PDR-Launch duration by 26 days.

By November 2008 most hardware and software development was complete, and testing continued. At this point, cost overruns were approximately $400 million. In the attempts to meet the launch date, several instruments and a cache for samples were removed and other instruments and cameras were simplified to simplify testing and integration of the rover. The next month, NASA delayed the launch to late 2011 because of inadequate testing time. Eventually the costs for developing the rover did reach $2.47 billion, that for a rover that initially had been classified as a medium-cost mission with a maximum budget of $650 million, yet NASA still had to ask for an additional $82 million to meet the planned November launch.

**Cassini**

2rd longest duration from PDR to Launch (1891 days, 61 months).

Removing this data point would reduce mean PDR-Launch duration by 23 days.

"The spacecraft was originally planned to be the second three-axis stabilized, RTG-powered Mariner Mark II, a class of spacecraft developed for missions beyond the orbit of Mars. Cassini was developed simultaneously with the Comet Rendezvous Asteroid Flyby (CRAF) spacecraft, but various budget cuts and rescopings of the project forced NASA to terminate CRAF development in order to save Cassini. As a result, the Cassini spacecraft became a more specialized design, canceling the implementation of the Mariner Mark II series."

**MAGELLAN**

3rd longest duration from PDR to Launch (1676 days, 54 months).

Removing this data point would reduce mean PDR-Launch duration by 16 days.

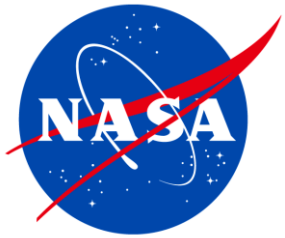
"Originally, Magellan had been scheduled for launch in 1988 with a trajectory lasting six months. However, due to the Space Shuttle Challenger disaster in 1986, several missions, including Galileo and Magellan, were deferred until shuttle flights resumed in September 1988. Intended to be launched with a new, liquid-fueled, Centaur-G shuttle deployable upper-stage booster, subsequently canceled after the Challenger disaster, Magellan had to be modified to attach to a less powerful solid-fueled, Inertial Upper Stage. The next best opportunity for launch would occur in October 1989.Further complicating the launch however, was the upcoming Galileo mission to Jupiter, which included a flyby of Venus. Intended for launch in 1986, the pressures to ensure a launch for Galileo in 1989, mixed with a short launch-window necessitating a mid-October launch, resulted in replanning the Magellan mission. Weary of rapid shuttle launches, the decision was made to launch Magellan in May 1989, and into an orbit that would require 1 year and 3 months before encountering Venus."

**Dawn**

4th longest duration from PDR to Launch (1442 days, 46 months).

Removing this data point would reduce mean PDR-Launch duration by 9 days.

"The status of the Dawn mission changed several times. The project was cancelled in December 2003 and then reinstated in February 2004. In October 2005, work on Dawn was placed in ""stand down"" mode, and in January 2006, the mission was discussed in the press as ""indefinitely postponed"", even though NASA had made no new announcements regarding its status. On March 2, 2006, Dawn was again cancelled by NASA. The spacecraft's manufacturer, Orbital Sciences Corporation, appealed NASA's decision, offering to build the spacecraft at cost, forgoing any profit in order to gain experience in a new market field. NASA then put the cancellation under review, and on March 27, 2006, it was announced that the mission would not be cancelled after all. In the last week of September 2006, the Dawn mission's instrument payload integration reached full functionality. Although originally projected to cost US$373 million, cost overruns inflated the final cost of the mission to US$446 million in 2007."





# SIMULATION MODELS

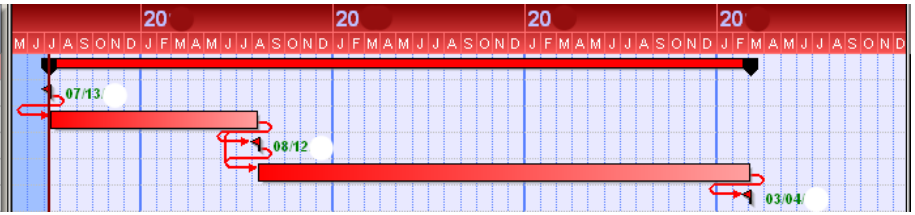
# Simulation Methodology

- Build top-level schedule simulation model in Primavera Risk Analysis (PRA)
- Apply deterministic duration estimates based on nominal plan
- Apply fitted duration distributions to the phases in the model
- Apply correlation
- Run Monte Carlo Simulation
- Plot resulting s-curves, confidence level in deterministic plan, 50% confidence level
- Note that since distributions are based on actual historical durations, no additional discrete risks are applied to this model

# Level 1 Models

- Level 1 Model consists of two activities:
  - ATP to PDR, Phase A & B (completed)
  - PDR to Launch, Phase C & D (historical uncertainty applied)
- Level 1 Model Variants
  - PDR to Launch distribution based on actual historical data
  - PDR to Launch distribution based on fitted Lognormal distribution
  - PDR to Launch distribution based on actuals < 1300 days PDR to Launch (4 outliers removed)

| ID | Description | Remaining Duration | Start | Finish | Remaining Cost |
|---|---|---|---|---|---|
| 0070 | Level 1 Model, Fitted | 1331 | 07/13 | 03/04 | $0 |
| 0080 | ATP | 0 | 07/13 | | $0 |
| 0090 | Sunk - ATP to PDR | 395 | 07/13 | 08/11 | $0 |
| 0100 | PDR | 0 | 08/12 | | $0 |
| 0110 | PDR to Launch | 935 | 08/12 | 03/03 | $0 |
| 0120 | Launch | 0 | 03/04 | | $0 |

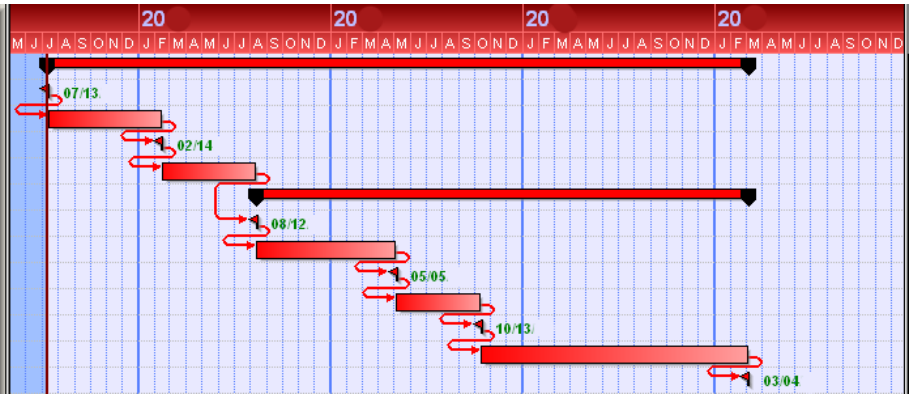


# Level 2 Models

- Level 2 Model consists of 5 activities
  - ATP to SRR, Phase A (completed)
  - SRR to PDR, Phase B (completed)
  - PDR to CDR, Phase C1
  - CDR to I&T Start, Phase C2
  - I&T Start to Launch, Phase D

- Level 2 Model Variants
  - Fitted Distributions, With correlation, no I&T outliers
  - Fitted Distributions, No correlation, no I&T outliers
  - Fitted Distributions, With correlation, I&T outliers
  - Fitted Distributions, No correlation, I&T outliers
  - Actual Distributions, With correlation
  - Actual Distributions, No correlation

| ID | Description | Remaining Duration | Start | Finish | Remaining Cost |
|---|---|---|---|---|---|
| 0390 | Level 2 Model, w Corr | 1331 | 07/13 | 03/04 | $0 |
| 0400 | ATP | 0 | 07/13 | | $0 |
| 0410 | Phase A | 216 | 07/13 | 02/13 | $0 |
| 0420 | SRR | 0 | 02/14 | | $0 |
| 0430 | Phase B | 179 | 02/14 | 08/11 | $0 |
| 0440 | PDR to Launch | 936 | 08/12 | 03/04 | $0 |
| 0450 | PDR | 0 | 08/12 | | $0 |
| 0460 | Phase C1 | 266 | 08/12 | 05/04 | $0 |
| 0470 | CDR | 0 | 05/05 | | $0 |
| 0480 | Phase C2 | 161 | 05/05 | 10/12 | $0 |
| 0490 | I&T Start | 0 | 10/13 | | $0 |
| 0500 | Phase D | 508 | 10/13 | 03/03 | $0 |
| 0510 | Launch | 0 | 03/04 | | $0 |



# Correlation Factors

## Model with I&T outliers

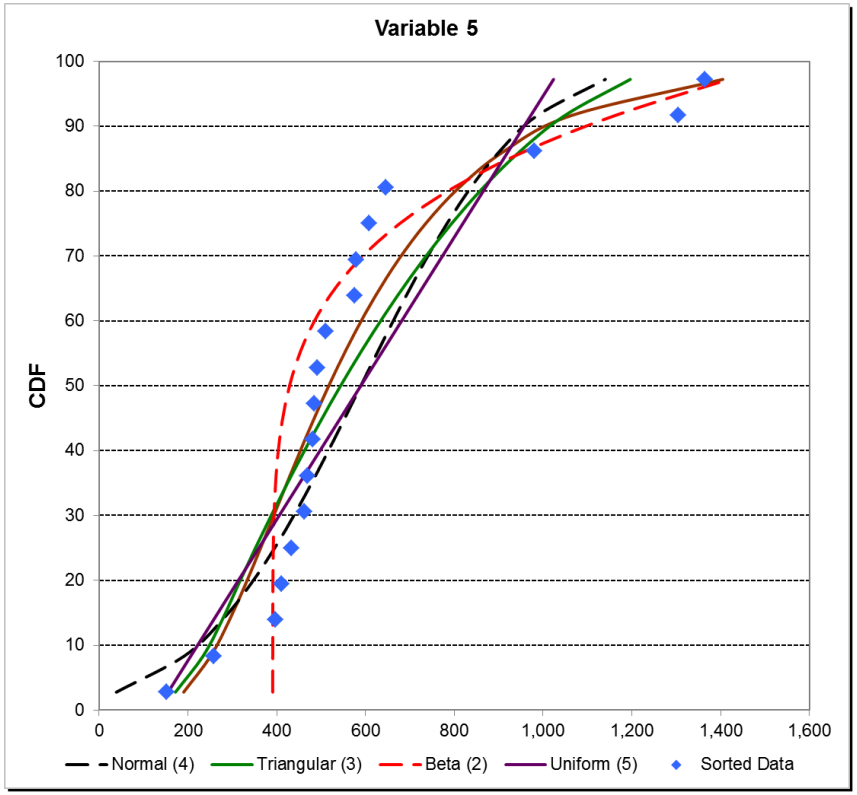
| | Phase C1 | Phase C2 | Phase D |
|---|---|---|---|
| Phase C1 | 1 | 31% | 48% |
| Phase C2 | | 1 | -12% |
| Phase D | | | 1 |

## Model without I&T outliers

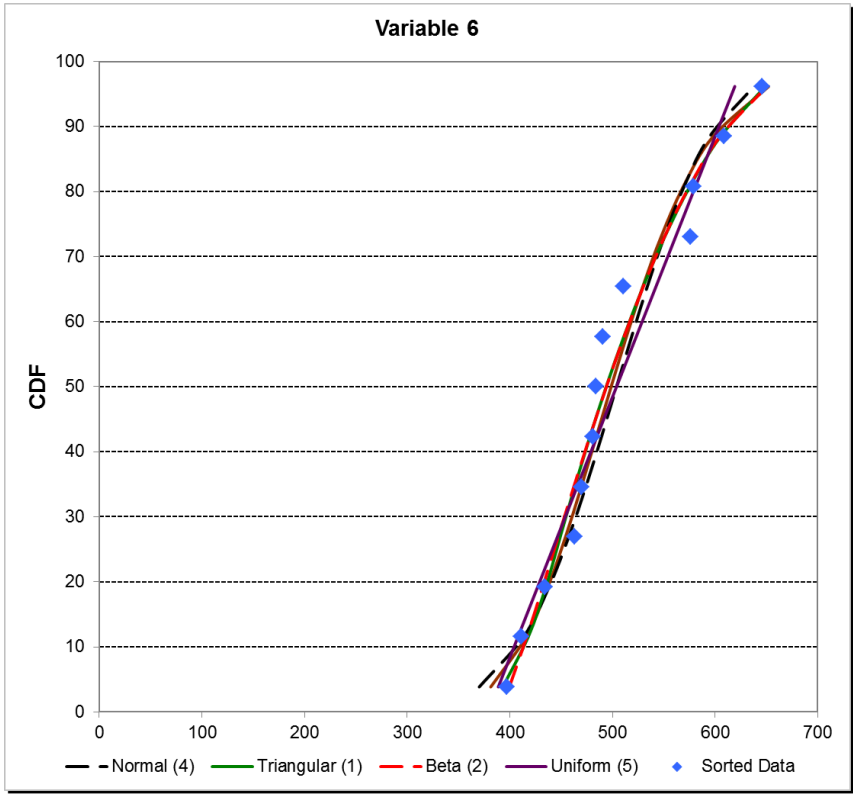
| | Phase C1 | Phase C2 | Phase D |
|---|---|---|---|
| Phase C1 | 1 | 31% | 42% |
| Phase C2 | | 1 | 8% |
| Phase D | | | 1 |

# I&T Outliers

## With I&T Outliers

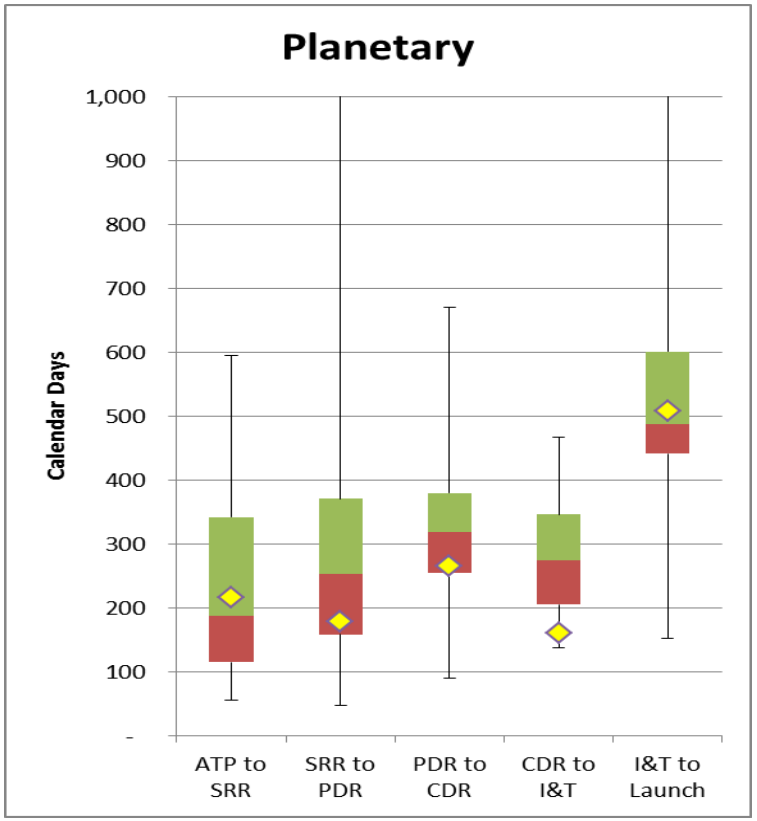


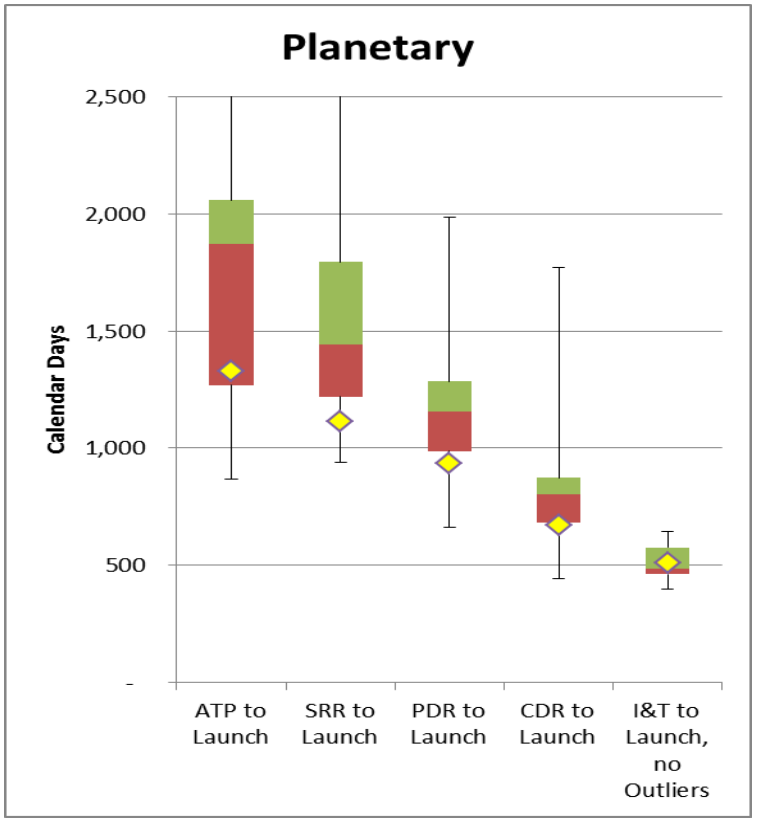

## I&T Outliers Removed



# RESULTS

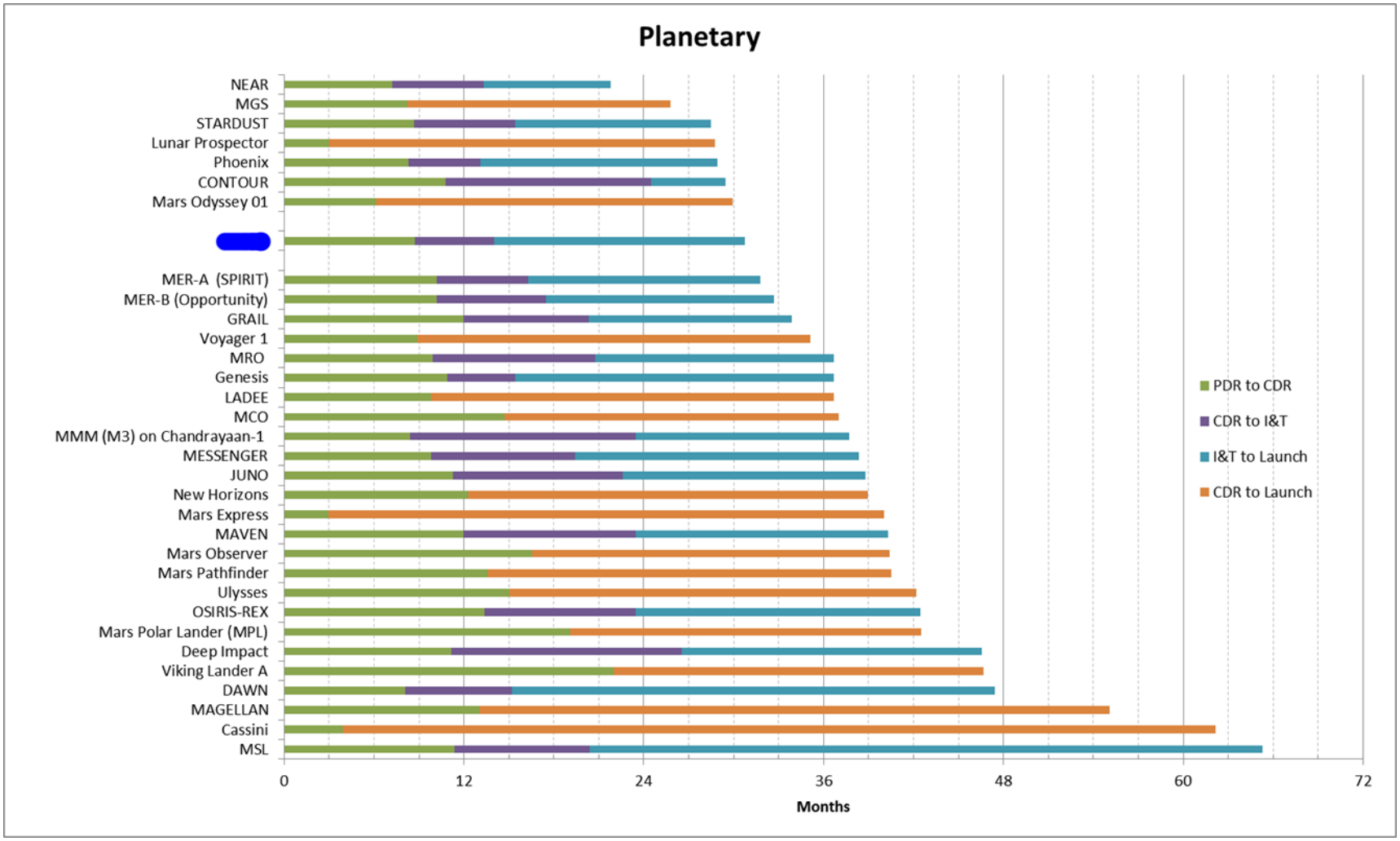
# Comparative Analysis
# Box & Whiskers Charts



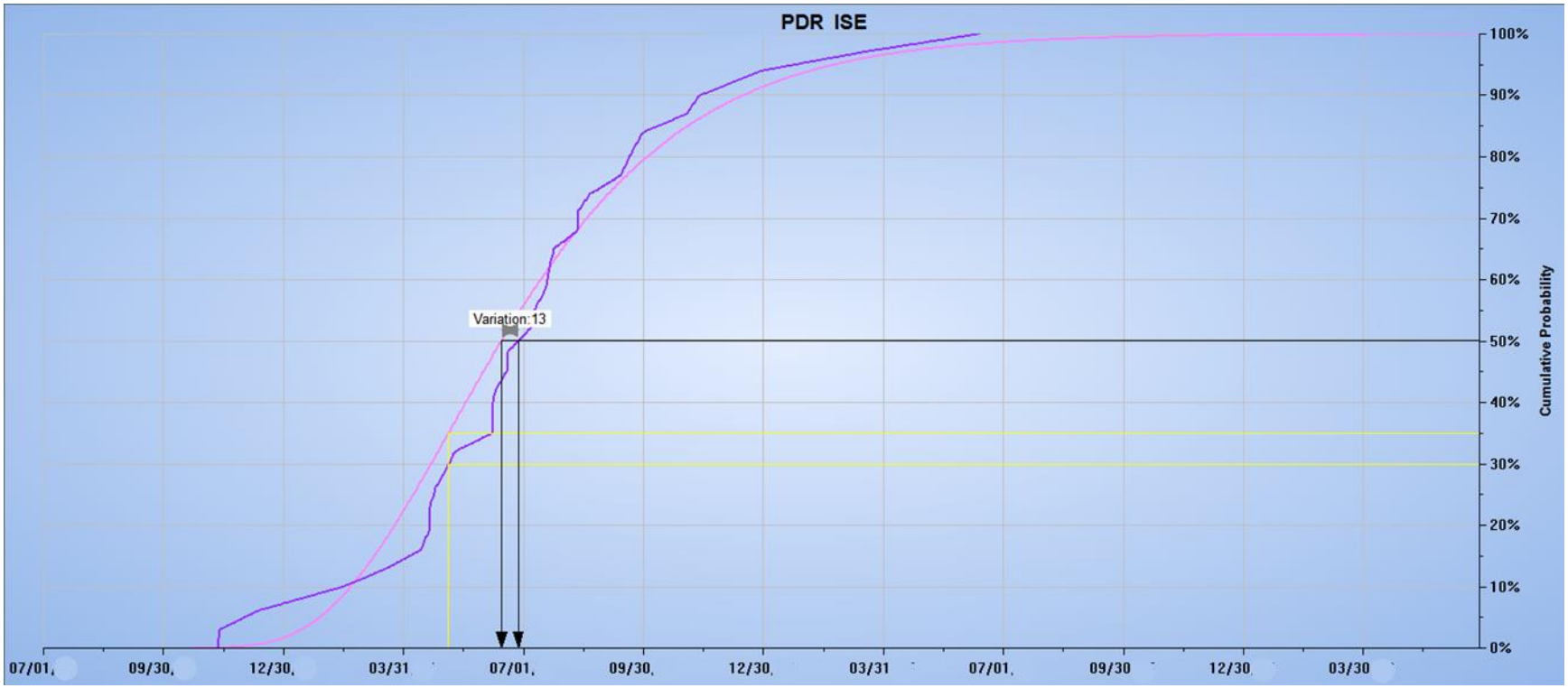




- The box and whiskers show quartile ranges.
- The yellow diamond is the hypothetical project planned duration.

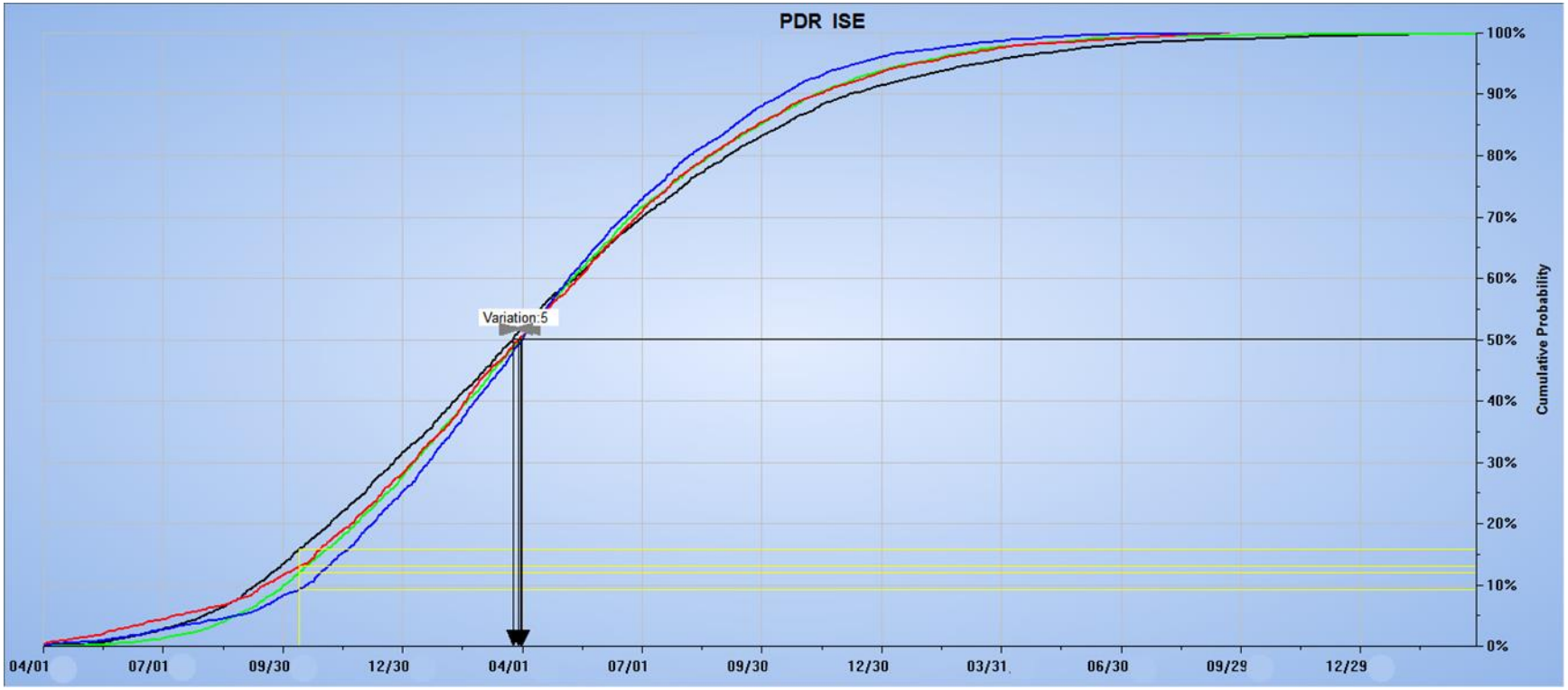
# Comparative Analysis Stacked Bar Chart



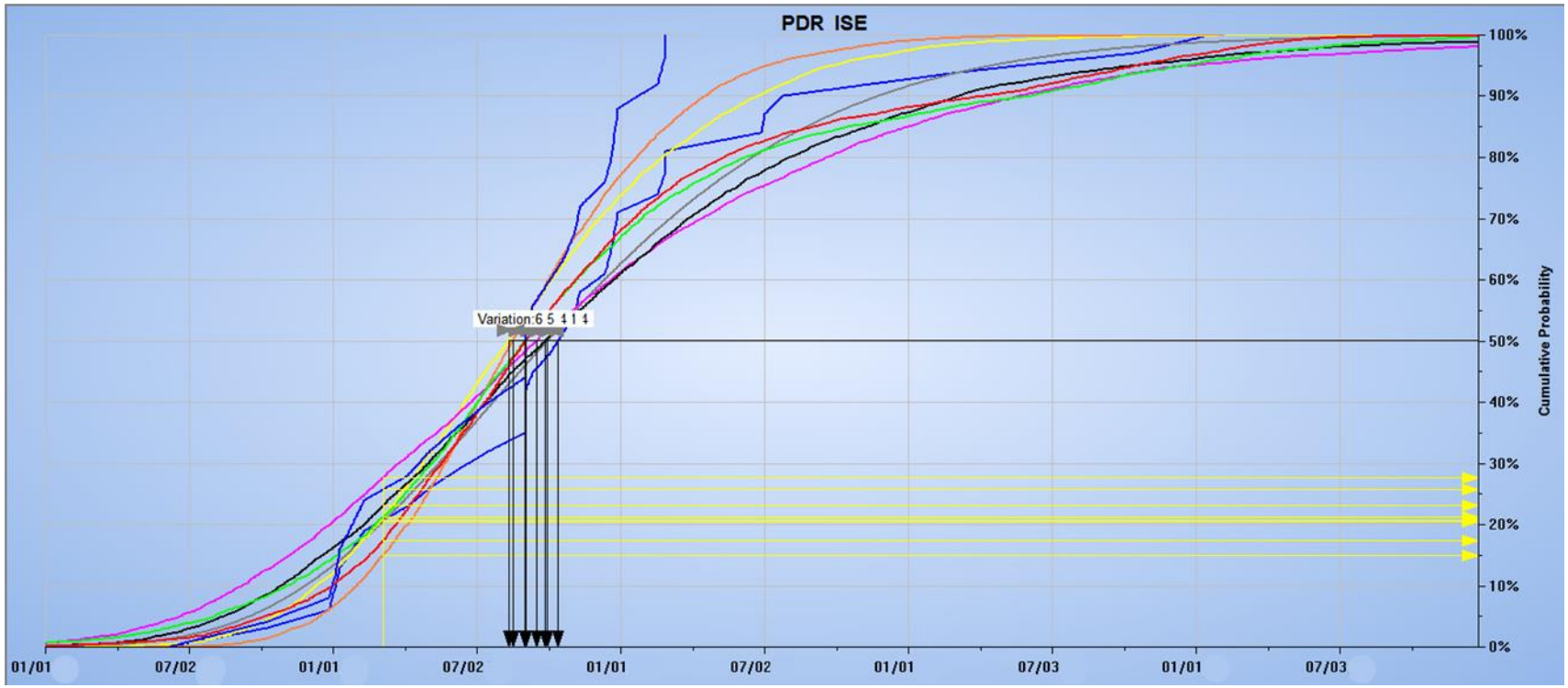
# Simulation Results
# CDR Milestone



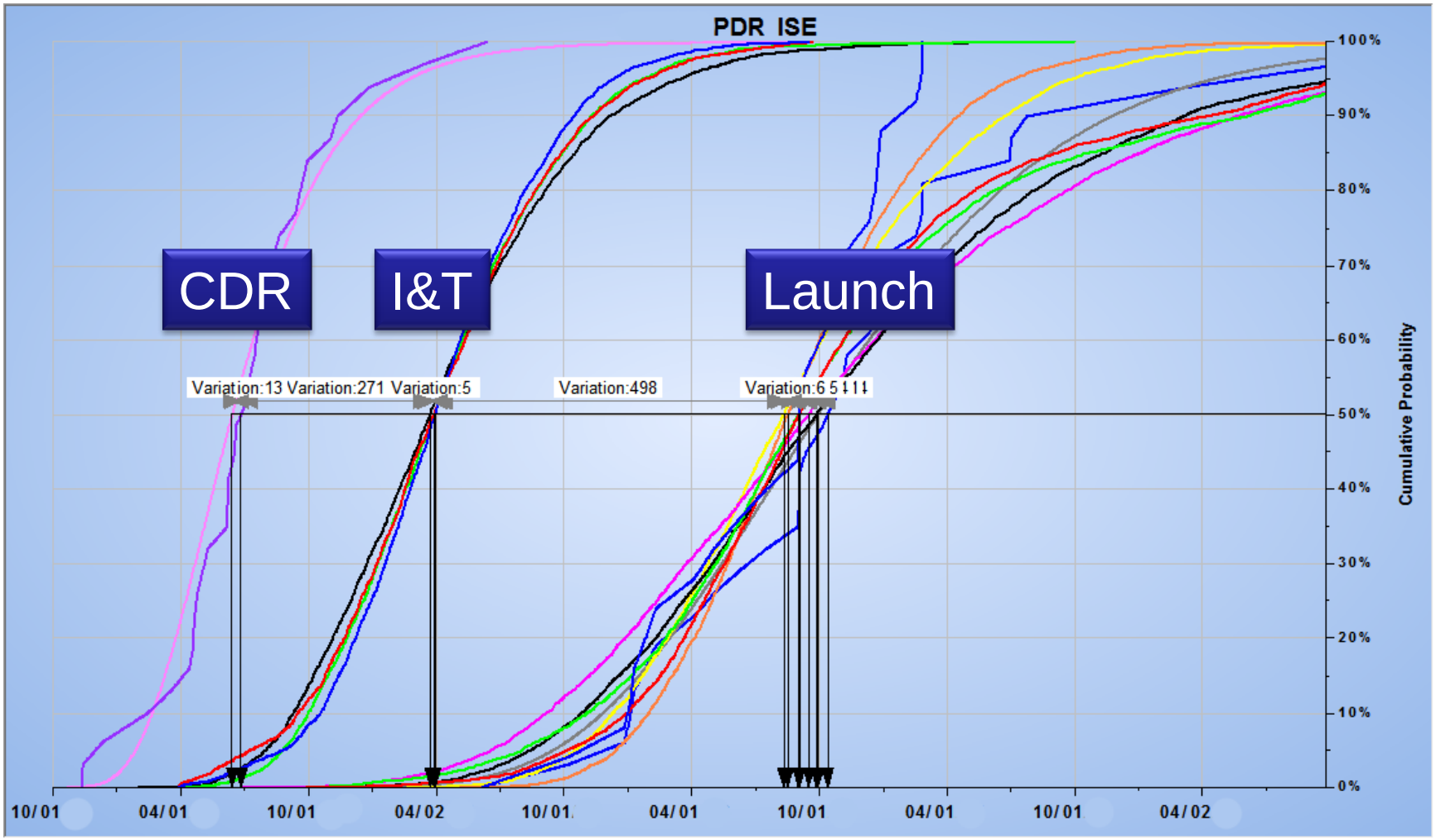
# Simulation Results
# I&T Start Milestone



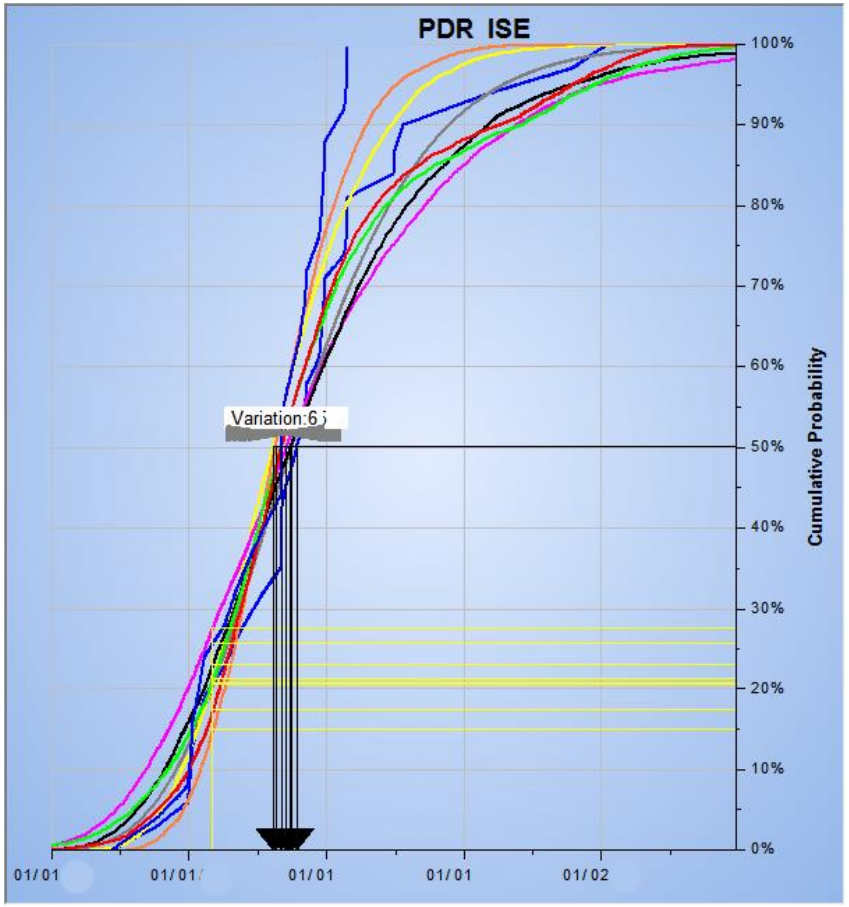
# Simulation Results
# Launch Date



# Rolling Wave Chart



# Executive Summary
# S-Curve




- The ISE is a top-down estimate based on the average duration and variation of similar projects
- Various level 1 and level 2 schedule simulation models were developed
- Based on these ISE models, the likelihood of meeting the 3/##/## opening day of the launch window ranges from 15-28%
- The 50% confidence level launch readiness date ranges from 8/11/## to 10/13/##
- If nothing is done to maintain schedule, then based on historical data, the project could launch 5-7 months late
- However, the project must launch during the 20## opportunity or face a 26 month delay to the next opportunity
- Various mitigation strategies can be employed to compress the schedule to meet the launch window, including working overtime or additional shifts
- Additional shifts may require additional resources above the planned reserves.

# CONCLUSIONS

# Conclusions

- Historical data analysis can be used to estimate the schedule uncertainty for a new mission.
- Analysis and removal of outliers can improve the quality of probability distributions.
- Weak correlation exists between phases of a project.
- Uncertainty distributions can be applied to high-level summary models.
- Intermediate milestones can be predicted as well as launch date.
- Results are consistent across various types of models.